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System Design Framework for Equity/ Fairness among Actors

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Abstract

Perceived unfairness has hindered participation and support from actors (i.e. decision makers and stakeholders), rendering some next generation systems solutions ineffective. This work develops a framework for system design by explicitly considering equity/fairness. Equity is looked at from the perspective of how financial costs and benefits are distributed among actors. Implications of different equity principles are explored using a case study about efforts to reduce aviation emissions. The study investigates aviation biofuels production involving farmers, biorefineries, airlines, aircraft/engine manufacturers, and taxpayers. An isoperformance approach is employed to identify the trade-off space in which burden for reducing emissions can be shared among the actors.

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Keywords: *equity, distribution of costs and benefits, shared burden and sacrifice, isoperformance, next generation systems*

1. Background

Observations to the next generation systems projects reveal the fact that most solutions involving multiple actors have experienced a delay or ended in a dispute. Efforts to modernize air traffic infrastructure in the U.S, for example, have been hampered by the disagreement about who should pay for the costs [1]. The aviation authority expects that airlines pay their share. Airlines, on the other hand, have been reluctant to invest in new equipment since they are not certain about the return. Another example is that policies aimed to restructure how airport slots are distributed among airlines ended up with some incumbent airlines suing the authority in court. In a different transport sector, some proposed high speed rail projects in the US get blocked as a result of a bickering among federal and state government on the question whether investments are worth the taxpayers' money [2]. There has been a historical precedent that private rail sector expects the government to take the initial risks before committing their resources [3].

Furthermore, the on-going efforts to combat climate change at international level are facing considerable hurdles on the issue of division of responsibilities among industrial and developing countries. At the U.S national level, the

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development of alternative energy from renewable sources has brought up questions about its impact on rural communities [4]. Concerns over impacts of renewable energy development to the rural communities have generated new thinking about equitable solutions. There have been some attempts to bring benefits to the local communities. Examples include bringing the manufacturing of wind turbine closer to the location of wind farm and training local workforce to maintain the facilities. Farmers who grow energy crops can expect reward from their endeavors by getting additional revenues from carbon sequestration [5].

Policymakers and other stakeholders do realize the importance of pursuing an equitable solution. For example, the NextGen Integrated Work Plan document included the phrase “equitable access to the national airspace system resources—both airports and airspace [for all users]” [6]. Similarly, there has been consensus among world leaders that the very concept of sustainable development depends on resolving the question of complex problem of allocation: “How can an equitable welfare for everyone be created without exhaustion or degradation of natural resources or ecosystems?”[7].

Dealing with competing stakeholders’ interests has been addressed in the literature. The usefulness of accommodating and anticipating potential conflicts through consultation via multiple channels has been demonstrated in the context of deregulation in the electricity transmission sector [8]. The so-called Quantitative WinWin negotiation method has been proposed to find non-dominated solutions during the negotiation process for defining and selecting system requirements [9]. Some methods have relied on the works found in the field of economics and psychology during the implementations (e.g. [10, 11]).

The objective of this paper is to present a framework for informing system design to achieve equitable solutions. The work complements the existing literature by putting forward a system design framework that explicitly quantifies the distribution of costs and benefits across a variety of equity principles.

The framework is based on the premise that solutions with perceived unfairness will render them ineffective. A next generation systems project takes place in an environment where no single actor can individually influence the overall system performance. Therefore, the participation of actors is a necessary condition for the project’s success.

2. System Design Framework

The design framework first describes a working definition and some principles of equity to clarify the basic concept of equitable solutions. A taxonomy is then developed to characterize some unique equity issues along three perspectives.

Besides the conceptual basis, the framework develops a method for quantifying the equity impact. An isoperformance algorithm is adapted to identify trade-off space for actors in terms of burden sharing. A way to quantify equity impacts using a sacrifice index metric is illustrated.

2.1. Definition of Equity concept

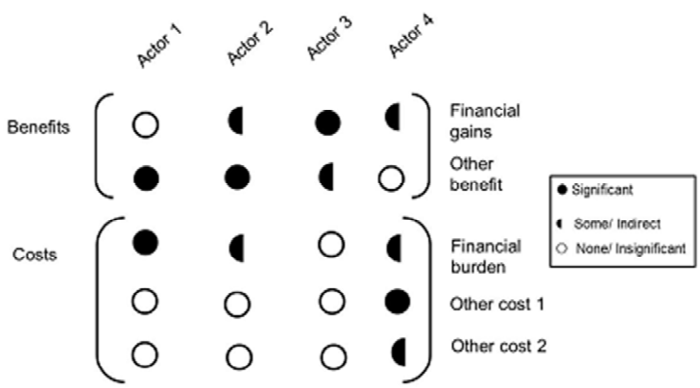

Fig. 1. An illustrative distribution of costs and benefits among actors

Equity or fairness has been long the subject of human discourse, whose philosophical underpinning can be traced back to the work of Aristotle. In this work, the concept of equity is interpreted as a fair distribution of costs and benefits among actors. Since costs and benefits can manifest in different forms, this paper focuses on quantifiable monetary gains and burdens. This simplification allows the concept to be made operational.

Fig. 1 illustrates a hypothetical distribution of costs and benefits involving four actors. The actors receive benefits in the form of financial gains and other less readily quantified benefits such as comfort and happiness. They also incur costs in the form of the financial burden and other nonfinancial costs such as risks to human health. The benefits and costs received and incurred by each actor are categorized in three levels: significant, some/indirect, and none/insignificant [12].

It can be seen, for example, that *Actor 3* receives significant financial gains but pays almost no costs. The opposite is experienced by *Actor 4*, who gets little in terms of financial gains and other benefits but suffers most of the consequences. This does not necessarily imply that *Actor 4* is responsible for paying for most of the financial costs. An actor can have a passive role but is still subject to costs of externalities (e.g. noise, air pollution, or second hand smoking).

Contrary to some misperceptions, equity does not necessarily always imply equality. Addressing equity is about ensuring all actors get equal access to opportunities but not equal results. In fact, as in the old communist system, making sure all actors get equal outcome will stamp initiatives and hinder innovations.

2.2. Equity principles

Some equity principles have been proposed (e.g. [13]). The principles address two main questions. First is how to allocate costs or burdens to actors. As the costs or other negative externalities will be felt by the overall system, who should incur the costs and by how much? Second is how to incentivize actors for pursuant of benefits. What is a fair way to attribute benefits or positive system performances to actors' contributions? Table 1 characterizes some of the equity principles relevant for the design of next generation systems.

Egalitarianism is arguably the most fundamental equity principle. As enshrined in the US constitution, every human being is born equal and therefore has the same right to use and operate resource. During the so-called gold rush in California in the early 20th century, gold mining had low entry barriers and the mining right was allocated on a "first come first available" basis. For this reason, access is only limited by actor's capability to make investment. A contemporary equivalent of the gold mining right is the right for using and exploiting outer space. The equal access can be based on the argument that each country has sovereignty over the air space above it.

Table 1. Examples of equity principles

Principle	Significance	Applications/metrics	Example(s)
Egalitarianism	Each actor entity has equal rights to access resources and operate	Allocation to the size/capability of actor entity	Gold mining right during the "gold rush" era
Spoiler of equilibrium pays	Pay according to contribution to the damages	Proportional to the responsibility on the causes of damage	Polluters pay for the cleaning up of an oil spill
Ability to pay	Actor claims access based on size of possessed resources	Highest bidder gets most benefits	Auction of telecommunication bandwidth
Grandfathering	Actor claims a right established by past usage/operations	Allocation based on the historical level	Division of airport slots
Merit	Actors are compensated in proportion of efforts/ risks	Proportional to risk taken: the higher risk, the higher benefits potential/ privileges	ATC service based on aircraft equipage level.

The other equity principles are grandfathering and merit. The proposed carbon cap and trade policy to reduce aviation emissions, for example, can be based on two these equity principles. The first option is to base the amount of free carbon allowances (i.e. the right to pollute) on the historical emission level (grandfathering principle). The second option is based on benchmarking of a certain fuel efficiency value (merit principle), which is set to about 12.6 kg life-cycle CO_2 per 1000 Revenue Passenger Kilometer [14]. As such, the grandfathering principle favors the incumbent airlines with relatively old aircraft fleet whereas the merit principle will reward airlines that invest in the more fuel efficient aircraft.

2.3. The taxonomy of equity issues

The taxonomy defines the characteristics of equity issues from three perspectives (Fig. 2). The first perspective looks at the organizational scope: intra-organization vs. inter-organization. Intra-organization takes place within a single industry in which actors are of the same type. Example includes utility companies within the electricity generation sector. The inter-organizations involve multi- type actors spanning across more than two industries. For example, at least three actors have stakes in the air traffic next generation systems: airlines, air traffic controllers, and airport operators. One main implication of this perspective is that the organizational scope can complicate a negotiation process in finding a compromise. The more independent the involved parties are the more complex the process becomes.

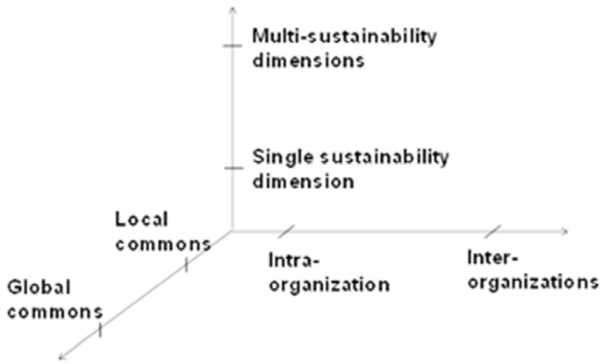

Fig. 2. The taxonomy of equity issues

The second perspective looks at the scope of impact: local *vs.* global commons, borrowing the terms from Hardin’s seminal work on the tragedy of the commons [15]. Local commons refer to shared resources whose exploitation has limited impacts. Overgrazing would be one example. By contrast, some shared resources such as atmosphere and hydrosphere (e.g. Ocean) has no political and geographical boundaries. Emitting carbon to the atmosphere is one example. In this context, the use of commons involves privatization of benefits (or profit) and socialization of costs (or risks). One main implication of this perspective is that it can inform the actors involved on what is at stake and its gravity.

The third perspective is the scope of sustainability impacts; that is to what extent the design solution addresses the three elements of sustainability indicators: economy, society, and environment. Sustainability development entails a (elusive) balance among these factors.

These three perspectives and their characterizations enable us to define equity issues in a more informative way. For example, at one end of the spectrum (i.e. intra- organization, local commons, and single sustainability impact) is a design problem of an aircraft engine within an organization. It can be represented as a network of competing objectives [16]. At the extreme end is the international issue to mitigate the economic, societal, and environmental impacts of climate change.

2.4. Individual actor vs. Common system objective

In order to provide a basis to quantify equity issue, a distinction needs to be made between objectives that belong to an individual actor, $\mathbf{o}_i$, and those to the common system, J_z^{System}.

Game theoretical framework informs us that individual actor performance depends on the decisions of other actors. Multi- criteria decision analysis framework suggests that actors attach preferences, $\mathbf{w}_i$ to a set of decision criteria [17]. The utility of an actor *i* can be defined as:

$$u_i := \mathbf{f}_i(\mathbf{o}_i, \mathbf{w}_i, \mathbf{o}_{i\neq j}), \qquad (1)$$

The common system objective, J_z^{System} transcends all $\mathbf{o}$ of actors. This view implies that very few (if none) of the actors actually associate J_z^{System} as their $\mathbf{o}$ (i.e. $J_z^{System} \neq \mathbf{o}$). In other words, pursuing J_z^{System} is not a *raison d'etre* for most actors. One can argue, for example, that, corporations exist to provide financial returns to their shareholders. Common system objectives such as protecting the environment or consumers’ interests would normally considered as secondary objectives.

2.5. Isoperformance solution search

The main idea of the isoperformance solution concept is to first set a desired performance target and then search model outcomes to find a set of satisfying solutions (i.e. iso-solutions). The isoperformance solutions set only exists if the number of decision variables are greater than the number of the common system objectives, J_z^{System} [18].

In the notional chart depicted in Fig. 3, one can see to which actors most of the burdens lie by comparing *Iso1* and *Iso3* solution. *Iso1* solution relies on Actor 2, who is responsible to realize *Decision Variable 3* to a required level and Actor 3, who is responsible to realize *Decision Variable 4 and 5.* In contrast, in *Iso3* solution, the burden is shifted to *Actor 1* and *Actor 4*.

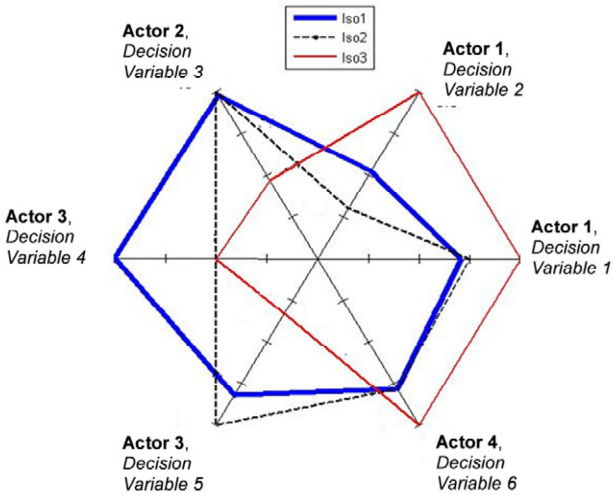

Fig. 3. Notional burden sharing solution space among actors

2.6. Measure of Actor Sacrifice

One particular measure that can be used to make the equity principle operational is a so-called sacrifice index [19]. Let c_i be a *sacrifice* function of actor *i* as a result of pursuing a common system objective. The function c_i is defined as the difference between the utility of an individual actor pursuing his individual objective u_i* and the utility of pursuing common system objective u_i^{System}:

$$c_i := u_i^* - u_i^{System} \quad (2).$$

The term sacrifice is used on the presumption that the utility of pursuing J_z^{System} is lower than self-interest utility. In other words, the extra measures of pursuing J_z^{System} result in extra costs within the time horizon. In a case where the sacrifice of an actor is negative, the actor actually gains a net benefit as a result of pursuing J_z^{System}.

Further, to measure the level of burdens imposed on each actor, a sacrifice index is defined as the ratio between sacrifice and self-interest utility:

$$Sacrifice\_Index = \frac{c_i}{u_i^*} \quad (3).$$

Such an index can capture actor costs or benefits relative to its maximum expected utility. This is related to the notion of equity based on the merit principle, which implies that actors should be compensated for the burden they bear [13].

The sacrifice index also allows an elicitation of the maximum threshold value that an actor is willing to commit. Such threshold can be a function of factors such as actor's financial capacity. The more resourceful an actor is, the greater the threshold will be. The feasible solution space will then be in the region where the sacrifice index is below actor threshold value.

3. Case Study

The case study investigates the production of biofuels for reducing aviation greenhouse gas (GHG) emissions, measured in CO_2 equivalent. The results were obtained from a life cycle assessment (LCA) study on the potential production of aviation biofuels in the U.S [20]. The actors considered involve policymakers, airlines, biorefineries, and farmers. Table 2 shows the element of costs and benefits for each actor. Only the shaded cost and benefit elements are investigated in this study.

Table 2. Definition of costs and benefits among actor entities

Actors	Costs	Benefits
Policymakers representing Tax Payers	– "Out of target" penalty – Subsidy costs	Averted negative impacts of climate change
Airlines	Additional costs burdens	Costs savings from extra CO_2 allowances
Biorefineries	Loss of investment	Profit (incl. revenues from refining co-products)
Farmers	Loss of investment	Profit (incl. additional incomes from Carbon sequestration

Policymakers set policy goal and design policy instruments to reduce GHG emissions. Bringing down the emission level to half of what it was in 2005 by 2050 is adopted as a policy goal. From policymaker's' perspective, there are costs associated with incentivizing the adoption of biofuels (i.e. subsidy costs). In addition, when the emission reduction target is not met, the tax payers will have to bear the "out of target" penalty costs. These costs equal the difference between actual and target emissions times the unit price of carbon.

Biofuels impact on airlines is defined in a context of a cap and trade policy in which airlines are given certain free carbon allowances. They will have to pay penalties when the actual emissions exceed the allowances. By adopting biofuels, airlines can either benefits from reduced penalty or pay additional financial burden when the price of biofuels is punitive. For biorefineries and farmers, the impacts are the consequences of investment in biofuel refining facilities and energy crops. The caveat here is that the definition of costs and benefits may not capture the full extent of the problem. The refinement will be a subject of further study.

4. Results and Analysis

The preliminary results are presented under three projections of oil price scenarios developed by the US Energy Information Administration [21]. The scenarios are designated as LowOil, ReferenceOil, and HighOil. The demand for air travel is assumed to be 2% per year over the period of 2013 to 2050. Improvement in aircraft fuel burn efficiency is assumed at a steady and conservative rate of 1% per year. The model looks at five potential next generation feedstocks that include camelina, algae, switchgrass, corn stover, and short-rotation woody trees.

4.1. Equity outcome under LowOil price scenario

In the LowOil price scenario, the study by Agusdinata et. al (2011) establishes that no feedstock is economically viable for biofuels production [20]. In this case, the tax payers will be the only relevant actor entity who will feel the impact. To avoid the penalty for missing out the carbon reduction target, policy makers will need to stimulate biofuels production. Failing to so will result in "out-of-target" penalty that depends on the price of carbon. The amount of the penalty costs under three carbon price scenarios is shown in Fig. 4. Clearly, the subsidy costs are much higher than "out of target penalty" costs in most setting of carbon price. The model suggests that subsidy costs will be justified when the price of carbon is around $150/ton.

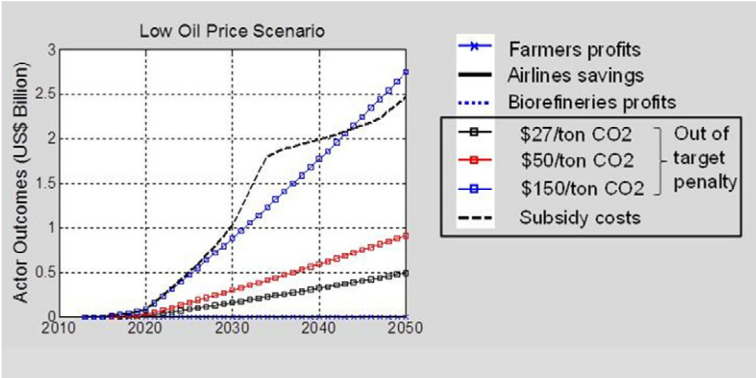

Fig. 4. Evolution of monetized costs and benefits in the LowOil price scenario

4.2. Equity outcome under ReferenceOil price scenario

In the ReferenceOil price scenario, only camelina-based fuels are economically viable. The realization occurs around the year 2022. To achieve the carbon reduction target, some level of subsidies is still needed. Fig. 5 shows the evolution of costs and benefits among actors. Subsidy costs are lower than "out of penalty" costs after 2040. In 2050, biorefineries profit is about twenty times larger than that of farmers.

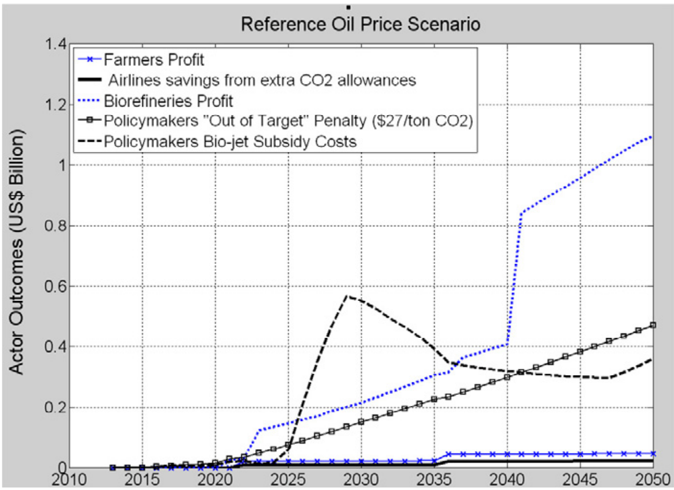

Fig. 5. Evolution of monetized costs and benefits under the ReferenceOil price scenario

4.3. Equity outcome under HighOil price scenario

In the HighOil price scenario, biofuels from a mix of feedstocks will manifest at different time frame. The supply mix constitutes corn stover, camelina, and switchgrass becomes economically viable starting from 2022. This is the time when there is enough demand to justify a full industrial production. Biofuels from short-rotation woody trees will be produced starting from 2030 and algae-derived fuel after 2040. As a result, no subsidies are needed to achieve the policy goal (Fig. 6). A stark contrast can be seen on the distribution of benefits among actors. Farmers will get only a small share of the benefits compared to relatively fair amount for airlines and windfall profit for biorefineries.

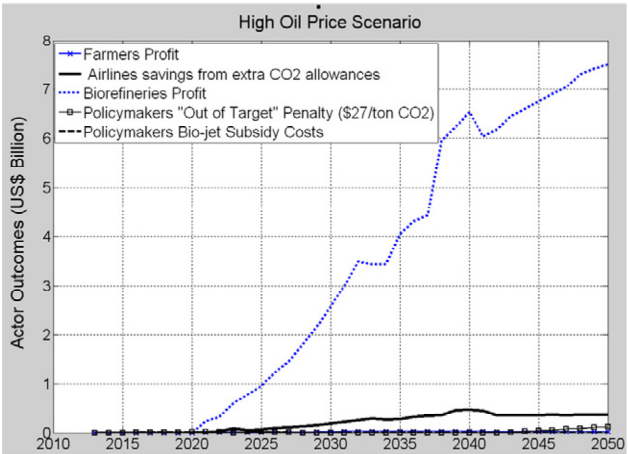

Fig. 6. Evolution of monetized costs and benefits in the HighOil price scenario

Based on these preliminary results, Fig. 7 summarizes the overall equity stance using the distribution of costs and benefits chart. Policymakers, hence the tax payers, will bear significant costs. The benefits are considered to be somewhat significant because some of them will only occur in the long term (e.g. avoidance of climate change). By contrast, biorefineries receive significant benefits while incurring little costs. This happens because under the model assumptions, biorefineries hold the trump card for initiating the production by dictating feedstock gate price to farmers and making investment only when there is sufficient demand to justify.

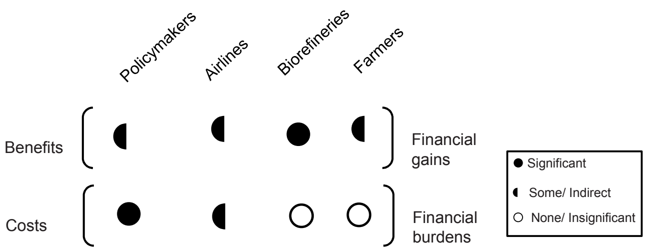

Fig. 7. Characterization of costs and benefits distribution among actors

4.4. Trade-off space for equitable solutions

The isoperformance approach has been implemented in another study on aviation GHG emissions involving airlines, biorefineries, and aircraft/ engine manufacturers [19]. The study presumed that actors take some additional measures to pursue common system objective J_z^{System}. When such measures require an actor to take risks beyond what he would normally take under normal condition, the model determines his sacrifice level. To put it into a context, there are little incentives for aircraft manufacturers to introduce new but risky advance technologies aircraft while they have long order backlogs on current technology aircraft. Similarly, to maximize profit, airlines will not adopt new technology aircraft at the rate that the policy goal requires them to do [22]. Doing so will imply that they take a risk beyond normal condition.

The study generated the trade-off space consisting of three isoperformance solutions. Within the trade-off space, the burden of achieving carbon emission reduction can be shifted among the three actors (Fig. 8). In this particular case, one solution will require airlines to make most of the sacrifice (*iso2* solution) whereas *iso1* and *iso3* solution put most of the burdens to the aircraft and engine manufacturers. The *iso1* and *iso3* solutions rely on a significant improvement in aircraft fuel efficiency to achieve carbon emissions reduction target.

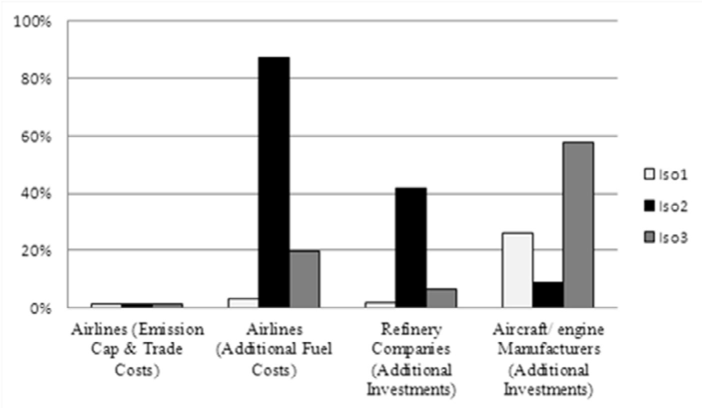

Fig. 8. Sacrifice level of key actors (with permission from JSSSE)

This insight can potentially be used as a basis for a merit based evaluation of actors' contribution to achieve common system goal. In the case when actors need to be compensated or reimbursed, sacrifice level can be used to proportionate the allocation.

5. Concluding Remarks

Dealing with equity is an intricate issue since it is often politically and emotionally charged. The design and implementation of next generation systems is especially prone to this condition. This work is motivated by the purpose of providing a basis to quantify equity impacts and make it operational. One of the main goals of the framework is to support a qualitative characterization of equity issue based on a quantitative basis under a wide variety of assumptions and scenarios.

The effectiveness of the approach depends on actors' willingness to reach a compromise. This is something that is not easy to promote. The challenge is to be able to convince relevant actors that it is in their best interests to jointly pursue common system objectives. The framework offered in this paper will make sure that their equity concerns will be addressed.

Future work will include financial uncertainties faced by actors. The National Research Council, for example, concludes that biorefineries would suffer financially when demand for biofuels is uncertain [23]. Applicability of the framework can also be tested in the case of the design of infrastructure for dealing with the environmental hazards resulting from a large scale production of nanomaterials. One relevant question is how relevant actors can share the responsibility for taking care of the toxic nanomaterials released to the environment.

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